AD-A104 449 BEN-GURION UNIV OF THE NEGEV BEERSHEBA (ISRAEL) DEPT--ETC F/G 20/12
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BEN GURION UNIVERSITY OF THE NEGEV

Dislocation-Induced Noises in Semiconductors at Low and High Temperatures.

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First Annual Technical Report

1st April 1980 - 1st April 1981

Approved for public release

Distribution unlimited

Prepared for:

European Research Office
United States Army
London, England

Contract Number: DAJA 37-80-C 0067

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

AD-A104 449

4. TITLE (and Subtitle)

6 Dislocation Induced Noises in Semiconductors at Low and High Temperatures.

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)

10 Samson Sam/Mil'shtein

8. CONTRACT OR GRANT NUMBER(s)

15 DAJA 37-80-C-0067

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Ben Gurion University of the Negev

P.O.B. 653, Beer-Sheva, Israel.

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS

ERO U.S. Army

223 Old Marylebone London, England.

11

12. REPORT DATE

May 1981

13. NUMBER OF PAGES

12 21

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

9 Annual technical rept. no. 1.
1 Apr 80-1 Apr 81,

15. SECURITY CLASS. (of this report)

Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Dislocations, Semiconductors, 1/f noise.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In continuation to research under Grant DAERO-78-6-115 this investigation was concentrated on better understanding of the dislocation structure involved in noise generation process. It is shown that noise power depends on unhomogeneities of dislocation structure especially on randomly distributed dislocation electrical barriers. The annealing of dislocation-point defect complexes does not influence the noise spectrum. It is difficult to find a proper explanation for this surprising result.

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CONTENTS

Introduction

The current research came in continuation of the one year program started under the DAERO-78-G-115 grant in January 1979. The main problem we faced in this research was an instability of the low frequency noise in heavily dislocated Si . Another problem which arose was due to the presence of dislocation-point defect complexes. Therefore the current research aims are to investigate in more detail the dislocation structure, noise dependence on inhomogeneities of the structure, noise power dependence on the polarity of the current.

Sample Preparation

The samples were prepared and plastically deformed by the methods described recently [1]. This investigation was carried out on laser irradiated and locally indented specimens. The small area ohmic contacts were made by technological methods developed recently [2].

In order to understand the role played by the internal dislocation electrical field (barrier) the intrinsic n-type Si wafers were cut into narrow strips 50 × 1 × 0.3 mm with the normal < 111 > to the big side (see Fig. 1).

The narrow strips were plastically deformed by diamond indentor perpendicular to [111] face of the strip in order to create the dislocation cluster in the center of narrow strip. Then six gold contacts were attached to the specimen (see Fig. 1).

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1. S. Mil'shtein, "Dislocation-Induced Noises in Semiconductors at Low and High Temperatures" Final Technical Report, Contract Grant DAERO-78-G-115 (May 1980).

2. S. Mil'shtein, Progress Invention Report DAERO-78-G-115 (May 1980).

Measurements

The characterization of dislocation clusters and their electrical fields in narrow samples were made by electron microscope.

Fig. 2a shows the etch-pits at the [111] surface. One can see the sharp gradient of the etch-pits at the border of dislocation cluster.

Fig. 2b demonstrates the presence of electrical field at the interface between the dislocated and normal parts of the crystal.

In order to measure the parameters of the dislocation internal electric fields we developed a new so called six point potential measurements (6-PPM). Let us briefly describe the idea of the method:

There are two current contacts attached to the opposite ends of a specimen (see Fig. 1). Contacts 1-4 are used for potential measurements. Measuring the voltage grop between contact 1 and 2 one can write:

$$V_{12} = J\ (\Gamma_1 + \Gamma_2) + \varphi_{12} \tag{1}$$

where J is the current flows along the specimen, φ_{12} is the dislocation electrical potential or barrier (DEB), Γ_1 and Γ_2 the bulk resistance between 1 and 2 contacts.

Electrometer I is used to measure the current, and electrometer II is used for the potential measurements.

Equation (1) can be written for various combinations of the contacts. For example:

$$V_{13} = J(\Gamma_1+\Gamma_2+\Gamma_3) + \varphi_{12} \tag{2}$$

or

$$V_{43} = -J(\Gamma_3+\Gamma_4) + \varphi_{34} \tag{3}$$

One can assume that $\varphi_{12} = \varphi_{34}$. The eq. 1-3 enables us to avoid the measurements of Γ_1 , Γ_2 , Γ_3 etc., which in turn requires the geometrical determination of the contact positions. The I-V characteristics provide the DEB value (φ_{12}). Comparing φ for various specimens with electron microscopy pictures one can even calibrate the electron microscopy contrast (brightness of the area - between dislocated and nondeformed part of the crystal) (Fig. 2).

The noise measurements were performed by two schemes. Fig. 3a presents the 4-term voltage fluctuation measuring system and Fig. 3b shows the 2-term current fluctuation measuring circuit. Fig. 4 and 5 present the 4-term voltage noise measured on plastically deformed and thermally annealed specimen w68. The $\log_{10} S_V(f)/\langle V\rangle^2$ is plotted versus $\log_{10} f(Hz)$ in frequency range from $3\cdot 10^{-2}$ to 10^{-2} Hz for both polarities of the bias voltage. One can see that both curves represent approximately the same 1/f like spectrum.

The measurements being repeated in two hours (Fig. 5) demonstrate some drop of the noise power.

The intrinsic silicon specimens have high resistivity and after plastic deformation their resistance is 20 times higher , that prevents us from using a true current source. There are two pairs of contacts at each specimen. Fig. 6 and 7 present the plot $\log_{10} S(f)|\langle J\rangle^2$ versus $\log_{10} f(Hz)$ in the frequency range $3\cdot 10^{-2}$ - 10^3 Hz for specimen No. 68 . Using one pair of contacts at this specimen we obtained approximately the same noise spectrum 1/f like both polarities of the current. (fig. 6) Using another pair of contacts we obtained different noise power for both polarities of current. (fig. 7) The value of the forward and reverse current shows that one of the contacts of last pair is somewhat non-ohmic.

The current noise measurements of the plastically deformed and thermally annealed specimen N69 are shown on figs. 8 and 9. One can find a strong dependence of the noise power on the current polarity.

Discussion

1) The noise measurements of the areas containing randomly distributed electrical fields around dislocations (see the bright areas on the electron microscopy pictures fig. 2) shows the noise power dependence on the current polarity: the difference in the noise is of about two orders of magnitude for reverse and forward direction of current. Recently we found this difference in a case of dislocation p-n junctions [1].

It must be pointed out that the potential measurements of φ_{12} value and electron microscopy show that electrically charged areas around dislocations are not true p-n junctions.

One can assume an existence of some average electrical field which fluctuates in time and modulates the conductivity of the specimen. Originally, this field could fluctuate because the number of electrons traped at defect sites changes in time and in turn the charge of defects (dislocations or complexes) fluctuates.

2) The plastically deformed and thermally annealed Si samples demonstrated 1/f like spectrum in frequency range 10^{-2} - 10^{3} hz. The most surprising result is that thermal annealing does not influence almost either noise power or the shape of the noise spectrum.

It is well established by many research groups [3-5] that plastic deformation creates various densities of point defects. The stable point defect-dislocation complexes could be formed as a result of both elastic and Coulomb type of interaction. So using the parameters appropriate to an fcc lattice R. Jonson [6] found that a vacancy will migrate around the edge dislocation to the compressional side. On the other hand, the charged edge-type dislocations being surrounded by clouds of charged point defects or impurities interact strongly with the latter [7]. Our C-V measurements [8] being performed on the same specimens (like N 68-69) had demonstrated that part of the dislocation-point defects remain after long thermal annealing. Thus two alternative conclusions are possible:

a) The observed 1/f noise spectra is a "pure dislocation" effect and dislocation-point defect complexes do not influence the noise generation process (?)

b) Neither the number of dislocation dangling bonds nor the density of defects influence the noise power but the internal randomly distributed electrical fields (surrounding the dislocation segments) are the main factor in observed phenomena. Recently, a detailed investigation carried out in our laboratory [9], showed that an extended (in intrinsic materials about 100 μm) electrical field exists around the dislocations in Si and Ge.

To clarify the picture additional research on the defect complexes behavior is necessary. More details about electrical barriers of the dislocated crystals are needed.

3 The 6-PPM method of the local electrical potentials was developed. This method provides straight information about the Fermi level position in locally damaged areas if one knows the Fermi energy in the initial material. It must be pointed out that any changes of Fermi level as a result of plastic deformation, ion-implantation radiation or other type of damage could be found by the 6-PPM method.

Comments

The aim of this research is better understanding of 1/f noise generation in dislocated crystals. Unfortunately it is very difficult to separate the dislocation effects from the activity of various point defects, since the dislocation-point defects complexes remain even after laser annealing.

The crystal containing misfit dislocations (misfits) seems to be a "pure" dislocation object. The misfits are uniform periodical structures with one type of dislocation. That still does not solve the problem of defect complexes because no data exists on annealing of "misfits". Our last year program includes the research on misfit dislocations induced noises. We could not accomplish the program because our cooperators in Germany are unable to grow the epitaxial layers containing the "misfits".

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Captions*

Fig. 1. Set-up for electrical measurements on defect semiconductor crystals.

Fig. 1.a. V-I characteristic of dislocated crystals.

Fig. 2. Electron microscopy of the Si crystal with dislocations

(a) interface between dislocated and dislocation-free parts of the crystal.

(b) electrical fields (bright areas) around single dislocations.

Fig. 3. Set-up for noise measurements:

(a) four-term voltage noise measuring circuit.

(b) two-term current noise measuring circuit.

Fig. 4. Four-term noise measurements on specimen w 68.

Fig. 5. Four-term noise measurements on specimen w 68 repeated in 2 hours.

Fig. 6. Two-term noise measurements on specimen w 68.

Fig. 7. Two-term noise measurements on specimen w 68 repeated in a 1/2 hour.

Fig. 8. Two-term noise measurements on specimen w 69.

Fig. 9. Two-term noise measurements on specimen w 69 repeated in 1 hour.

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* The noise measurements on Figs. 4-9 are accompanied by detailed information printed at the left side of each figure.

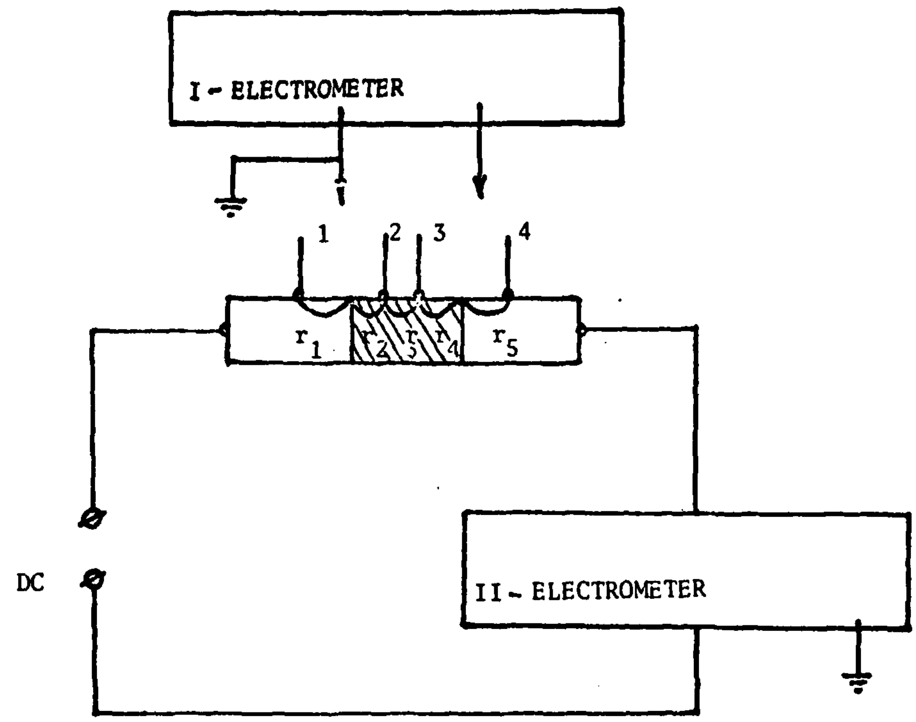

Fig. 1

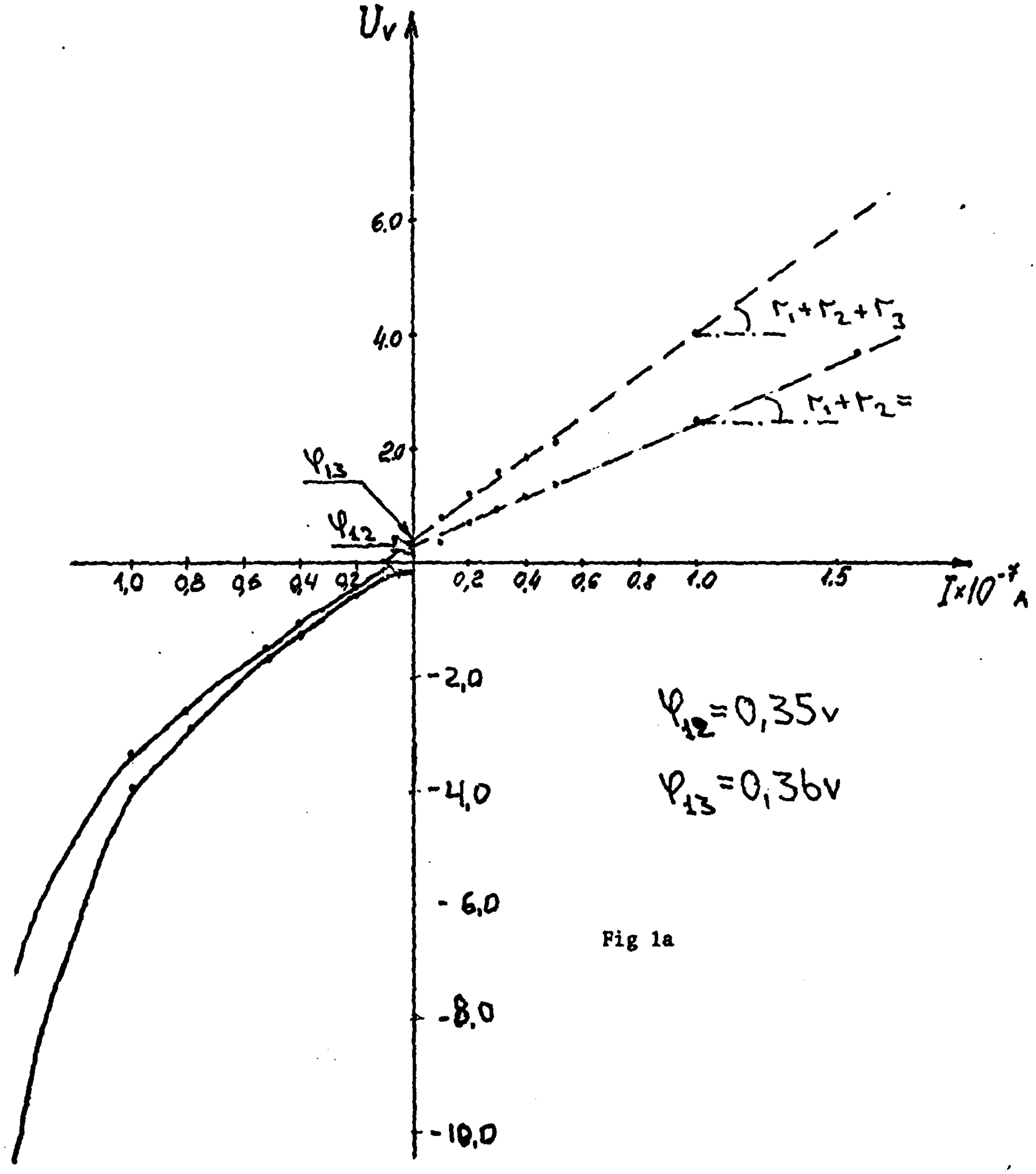
U_V
6,0
4,0
2,0
-2,0
-4,0
-6,0
-8,0
-10,0
1,0 0,8 0,6 0,4 0,2
0,2 0,4 0,6 0,8 1,0 1,5
$I \times 10^{-7}$ A
$r_1+r_2+r_3$
$r_1+r_2=$
φ_{13}
φ_{12}
$\varphi_{12}=0,35v$
$\varphi_{13}=0,36v$

Fig 1a

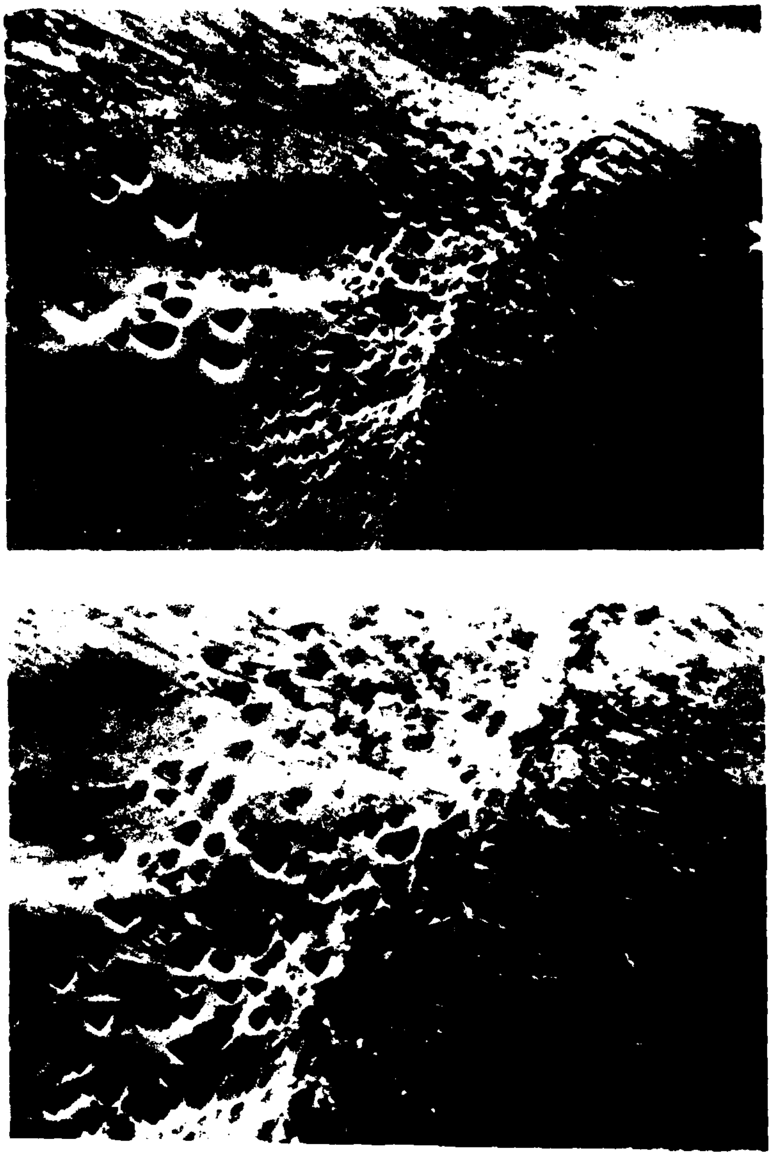

Fig. 2

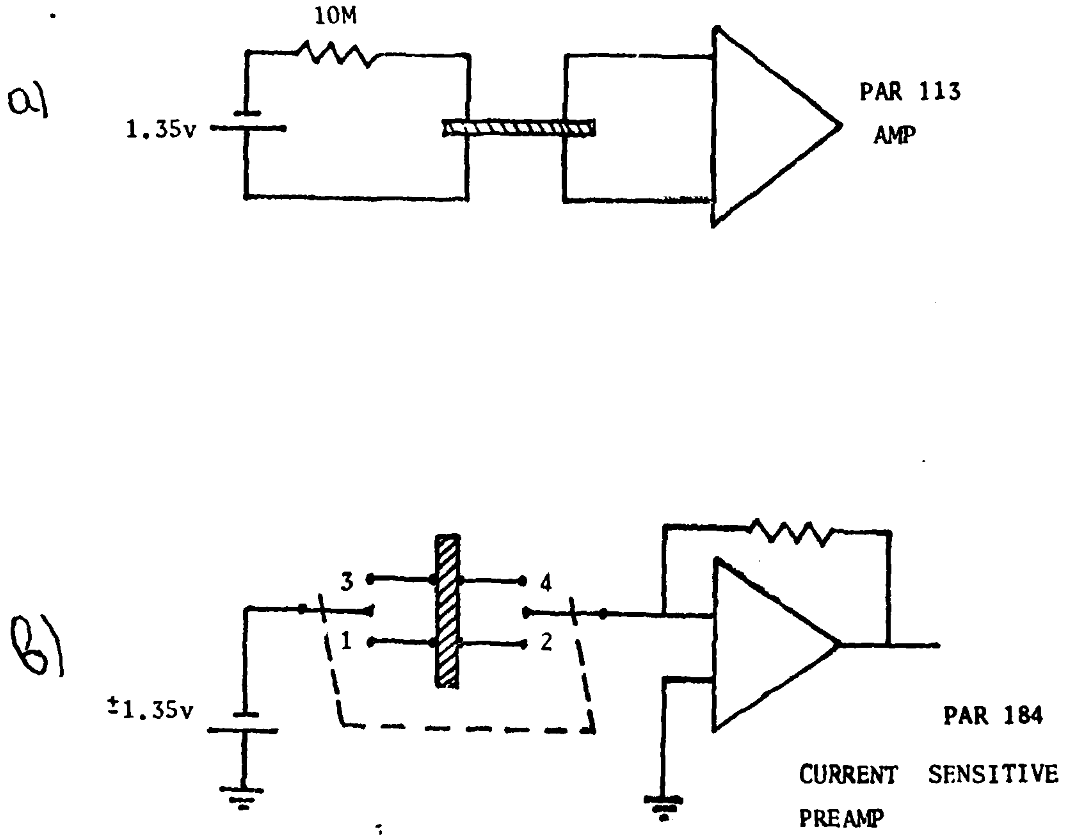
a)
10M
1.35v
PAR 113
AMP
b)
3
4
1
2
±1.35v
PAR 184
CURRENT SENSITIVE
PREAMP

Fig 3

TIME

● FILE 1 14 30
DISLOCATED SI (S.M.) 300K I=1.35V/10M I+(B1) I-(A1) V+(B2) V-(A2)
SPEC(2,1)=10*<V>, 113 AC .03-10K HZ G=1000 3322LPMF G=1 100HZ

FILE 2 SUBTRACTED AS BACKGROUND

<V> = .3570

▫ FILE 3 6 26 80 14 53
DISLOCATED SI (S.M.) 300K I=-1.35V/10M I+(B1) I-(A1) V+(B2) V-(A2)
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FILE 2 SUBTRACTED AS BACKGROUND

<V> = -.4199

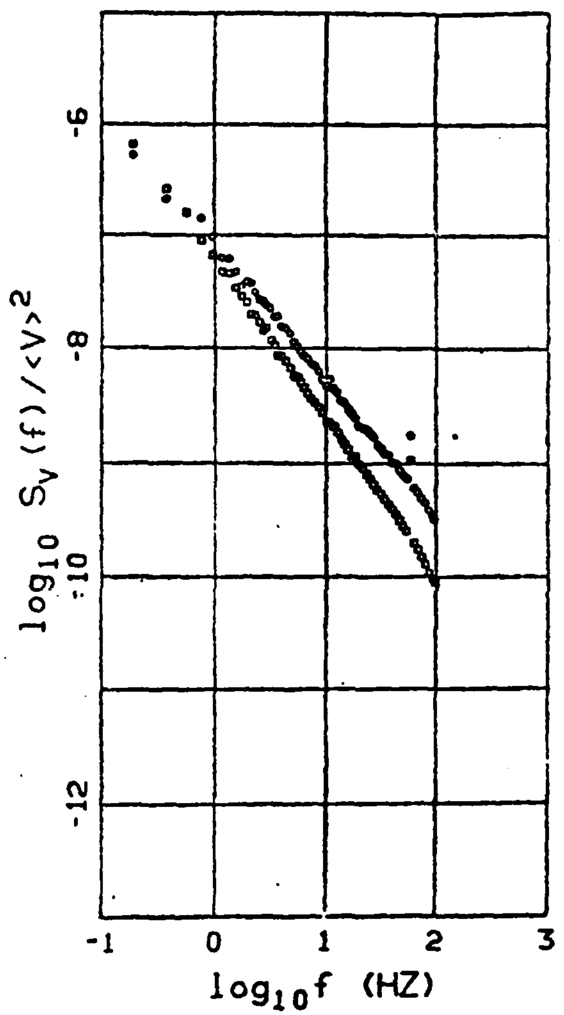

Fig 4

TIME

● FILE 4 16 27
DISLOCATED SI (S.M.) 300K I=1.35V/10M I+(B2) I-(A2) V+(B1) V-(A1)
SPEC(2,1)=10*<V>. 113 AC .03-10K HZ G=1000 3322LPMF G=1 100HZ

FILE 6 SUBTRACTED AS BACKGROUND

<V> = .6225

▫ FILE 5 6 26 80 16 54
DISLOCATED SI (S.M.) 300K I=-1.35V/10M I+(B2) I-(A2) V+(B1) V-(A1)
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FILE 6 SUBTRACTED AS BACKGROUND

<V> = -.5972

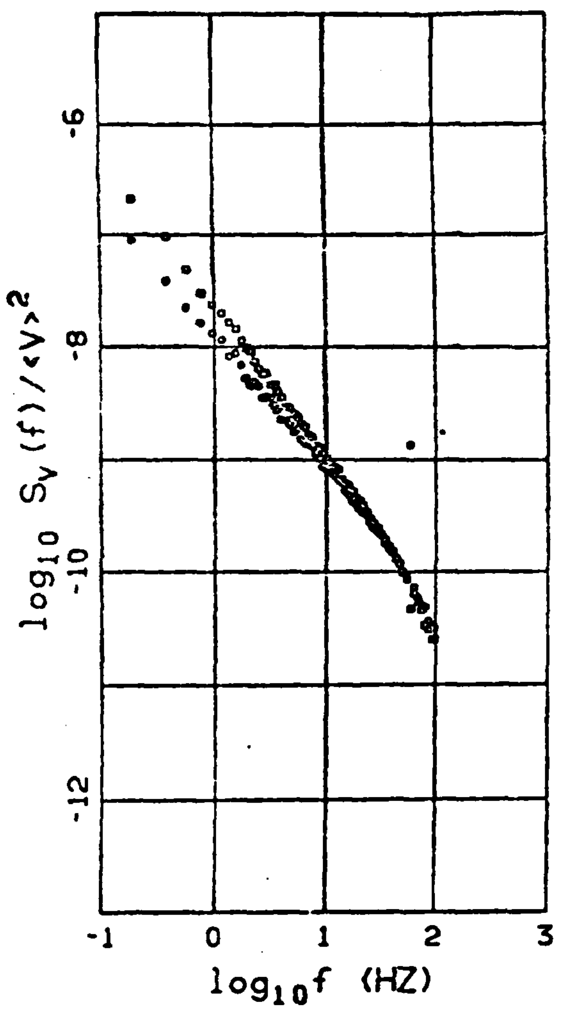

Fig 5

TIME

- FILE 9   9 59
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  <I> = 6.47E-08

- FILE 10   6 27 80   10 4
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  FILE 11 SUBTRACTED AS BACKGROUND

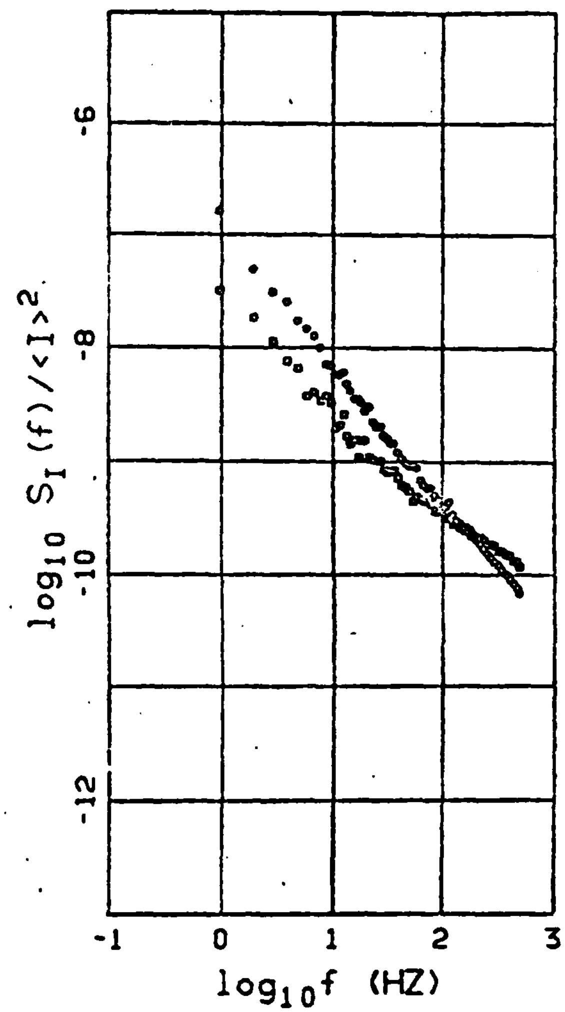

Fig 6

TIME

• FILE 14 10 26
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FILE 15 SUBTRACTED AS BACKGROUND

<I> = 5.80E-09

▫ FILE 16 6 27 80 10 43
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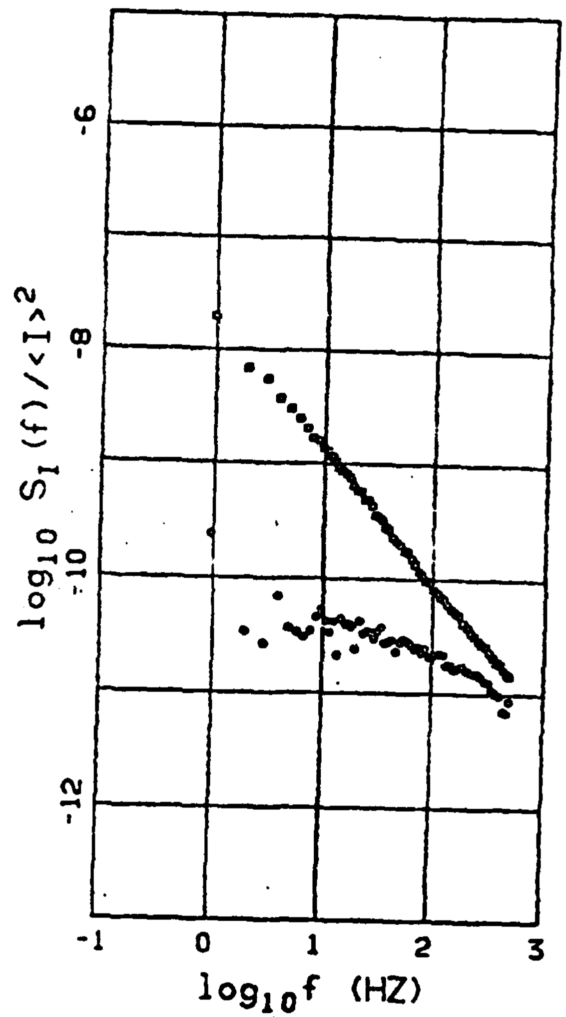

Fig 7

TIME

- FILE 17 11 15
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  SPEC(2,1)=184 MON. 113 AC .03-10K HZ G=1000 3322LPMF G=1 500HZ

  FILE 18 SUBTRACTED AS BACKGROUND

  <I> = 5.12E-09

- FILE 19 6 27 80 11 30
  W69 DISLOCATED SI (S.M.) 300K V=-1.35V (AB) . (BB) 184 1E-7A/V
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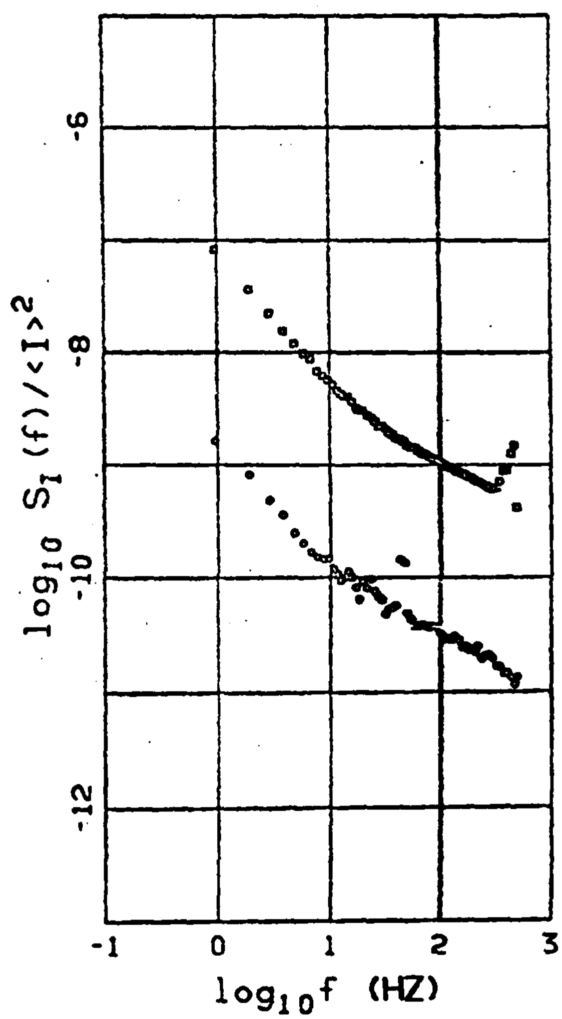

Fig 8

TIME

● FILE 20 12 38
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<I> = 9.91E-08

▫ FILE 21 6 27 80 12 41
W69 DISLOCATED SI (S.M.) 300K V=1.35V (A7) , (B7) 184 1E-7A/V
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<I> = 1.00E-07

▲ FILE 22 6 27 80 13 5
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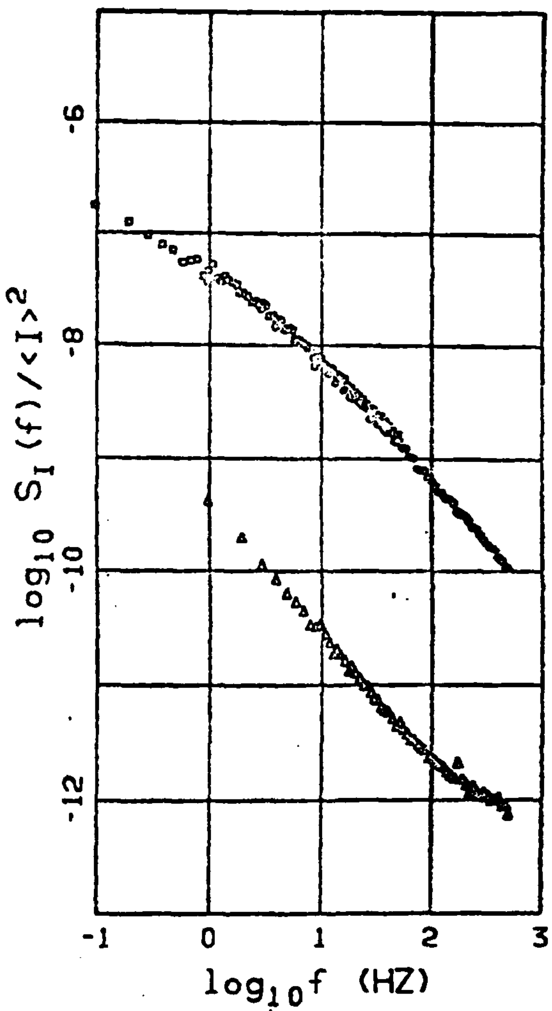

Fig.9

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